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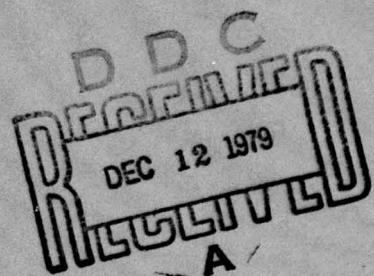
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Preliminary Assessment of an Automated System for Detecting Present Weather

H. ALBERT BROWN

26 June 1979



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METEOROLOGY DIVISION PROJECT 6670

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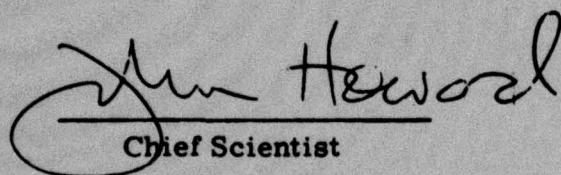


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This report has been reviewed by the ESD Information Office (OI) and is releasable to the National Technical Information Service (NTIS).

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FOR THE COMMANDER



John Howard
Chief Scientist

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Preface

The systems programming carried out by Mrs. Mary Hermann and Mrs. Joan Ward under the Regis and SASC contract is gratefully acknowledged. Many individuals from the Air Force Geophysics Laboratory assisted in this program; in particular, Mr. Leo Jacobs and Mr. Ralph Hoar extended excellent cooperation and field support in the operation of the AFGL Weather Test Facility at Otis AFB, Massachusetts. In addition, the author is grateful to Dr. Stuart Muench and Mr. Donald Chisholm for valuable discussions concerning the program and to Mr. Chisholm for many helpful comments on the paper. The author wishes to acknowledge the assistance of Miss Karen Sullivan in typing the manuscript.

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Contents

1. INTRODUCTION	9
2. AFGL WEATHER TEST FACILITY	11
3. DESCRIPTION OF AUTOMATED SENSORS	12
3.1 Transmissometer	12
3.2 Forward Scatter Meter	13
3.3 Back Scatter Meter	13
3.4 Nephelometer	13
3.5 Temperature-Dewpoint Set	14
3.6 Wind Direction and Speed Instrument	14
3.7 Rain Gage	14
4. WEATHER DISCRIMINATION BY SENSORS	15
4.1 Scatter Diagram Analysis	15
4.2 Time Section Analysis	19
5. PRESENT WEATHER DECISION TREE PROGRAM	26
5.1 Selection of Weather Elements	26
5.2 Obstruction to Vision Program	28
5.3 Present Weather Program	30
5.4 Examples of Observations	30
5.5 Preliminary Results	34
6. CONCLUSIONS	36
REFERENCES	37

Illustrations

1. Configuration of Instrumented Towers and Ground Site at AFGL Weather Test Facility, Otis AFB	11
2. Comparison between Transmissometer and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Fog	16
3. Comparison between Back Scatter Meter (Videograph) and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Fog	17
4. Comparison between Transmissometer and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Snow	18
5. Comparison between Back Scatter Meter (Videograph) and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Snow	20
6. Comparison between Transmissometer and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Rain	21
7. Comparison between Transmissometer and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Drizzle	22
8. Time Series of Atmospheric Extinction Coefficient (1-min Averages) Measured by Forward Scatter Meter at the 57-m (A-200), 48-m (A-150), 29-m (A-100) and 16-m (A-50) Levels of Tower A and at the 3-m (FSM X) Level of Ground Site X on 4-5 November 1978 during Fog. FAA Weather Observations made at Otis AFB are plotted above the time axis	23
9. Time Series of Atmospheric Extinction Coefficient (1-min Averages) Measured by Forward Scatter Meter at the 57-m (A-200), 48-m (A-150), 29-m (A-100) and 16-m (A-50) Levels of Tower A and at the 3-m (FSM X) Level of Ground Site X on 4 November 1978 during Ground Fog	24
10. Time Series of Atmospheric Extinction Coefficient (1-min Averages) Measured by Forward Scatter Meter at the 57-m (A-200) and 29-m (A-100) Levels at Tower A and at the 3-m (FSM X) Level at Ground Site X and also by Nephelometer (NEPH) at the 3-m Level at Ground Site X on 7 November 1978 during Fog. FAA Weather Observations are plotted above the time axis	25
11. Time Series of Atmospheric Extinction Coefficient (1-min Averages) Measured by Forward Scatter Meter at the 57-m (A-200) and 29-m (A-100) Levels at Tower A and at the 3-m (FSM X) Level at Ground Site X and also by Back Scatter Meter (VIDEO) at the 3-m Level at Ground Site X on 7 February 1979 during snow. FAA weather observations are plotted above the time axis	26
12. Symbols for Weather, Obstructions to Vision and Precipitation Intensity. Closed circles opposite symbols denote inclusion in the Present Weather Program. Open circle denote inclusion through observational frequency. (From <u>Federal Meteorological Handbook No. 1</u>)	27

Illustrations

13. Flow Charts of Obstruction to Vision and Present Weather Determination Program	29
14. Example of One Hour of Present Weather Program Output at 2000 GMT, 28 August 1978. FAA weather observations are plotted at extreme right	32
15. Example of One Hour of Present Weather Program Output at 0200 GMT, 7 November 1978. FAA weather observation is plotted at extreme right	33
16. Example of Verification of One Month (November 1978) of Obstruction to Vision Observations Generated by Present Weather Program with FAA Weather Observations	35

Preliminary Assessment of an Automated System for Detecting Present Weather

1. INTRODUCTION

Since the inception of weather services, human observers have been required to determine visually the types of weather occurring at a given time. The present-day Air Force, in spite of technological advancement, is more dependent than ever on timely weather observations. The need for accurate, detailed real-time aviation weather reports to support fixed-base operations has intensified.¹ Large aircraft are especially vulnerable to variations in weather during landings and take-offs because of their lack of maneuverability and slow recovery time at low speeds near ground. In addition, all pilots still have the requirement for visual orientation at decision height.

Weather support as currently supplied is highly labor-intensive,² therefore, expensive, and marginally adequate in those cases where rapid-changing hazardous weather events are directly affecting the last few minutes of an aircraft's landing approach. It becomes apparent upon consideration of recent advances in

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1. Beran, D. W., Hooke, W. H., Little, C. G., and Coons, F. (1977) Airport Weather Service: Some future trends, Bull. Am. Meteorol. Soc. 58(No. 11): 1182-1186.
2. Lundquist, James A. (1977) Automation - Some potential applications to aviation weather, Bull. Am. Meteorol. Soc. 58(No. 11):1161-1163.

automation and communication techniques that the time has come to automate the weather observing function.

Hill³ in 1966 summarized the progress made in automation of weather, beginning with the first automatic weather station in 1945, which reported wind speed, direction and pressure and continuing to 1953, when altimeter setting, accumulated precipitation, temperature and relative humidity had been added. Again in 1975, Hill⁴ related the fact that few present weather elements had been observed objectively and described efforts at the Test and Evaluation Division of the National Weather Service to attack some of these problems, for example, freezing precipitation, hail, and thunderstorms.

Tahnk and Lynch⁵ presented an account in 1978 of the development and installation of an airfield automated weather system (MAWS) to demonstrate the feasibility of automated observing and forecasting, using low-cost microcomputers. In addition to the more common automated parameters such as wind and temperature, they detailed the automation of cloud base height, visibility and the generation of additional displays of sea level pressure, twenty-four hour maximum and minimum temperatures, probability forecasts of cloud height and visibility, and such critical air base concerns as runway cross wind components, wind-chill temperature and maximum wind gusts. Thus, as technology has advanced, many useful parameters have been included in automated systems, but the subjectively-determined present weather elements have remained essentially untouched.

Several methods, utilizing different instruments, are currently under consideration for the automation of present weather. Moroz⁶ noted that the rotating-beam-ceilometer provides distinctive returns during rain, snow, and fog, and that these characteristics are also apparent in measurements made by a lidar ceilometer.

Interest has also been evidenced recently in the possibility of identifying weather through the observation of forward scatter of a laser beam. Earnshaw et al⁷ in a

3. Hill, A. N. (1966) Automatic Weather Stations in the U.S. Weather Bureau – Past, Present, and Immediate Future, Technical Note No. 82, Automatic Weather Stations, WMO No. 200, TP 104, WMO Geneva, pp. 19-37.
4. Hill, A. N. (1975) Automated objective observation techniques for present weather elements, Proc. WMO Technical Conference on Automatic Weather Stations (TECAMS), Washington, D. C., 14-19 Feb. 1975, (WMO No. 420).
5. Tahnk, W. R., and Lynch, R. H. (1978) The Development of a Fixed Base Automated Weather Sensing and Display System, AFGL-TR-78-0009, AD A054 805.
6. Moroz, Eugene Y. (1977) Investigation of Sensors and Techniques to Automate Weather Observations, AFGL-TR-77-0041, AD A040 747.
7. Earnshaw, K. B., Wang, T., Lawrence, R. S., and Greunke, R. G. (1978) A feasibility study of identifying weather by laser forward scattering, J. Am. Meteorol. 17:1476-1481.

recent publication described these efforts to differentiate clear air, rain, snow, hail, and fog with a prototype laser instrument. Preliminary observations led to the suggestion that such a technique is feasible. However, the reliability of identifying precipitation types still awaits assessment through collection of more weather data at different seasons of the year and at varied locations.

This report presents preliminary results of research in determining objectively the observation of weather, using an automated array of weather sensors in conjunction with a decision tree program.

2. AFGL WEATHER TEST FACILITY

For the past two years, the Air Force Geophysics Laboratory has operated a weather test facility (WTF) at Otis AFB, Massachusetts, with a threefold objective: (1) to serve as a base for testing new sensors for Air Force use; (2) to provide a data base for weather forecasting technique development; and (3) to serve as a platform on which to test and improve weather automation methods. A general configuration of the facility is shown in Figure 1. The central area is a

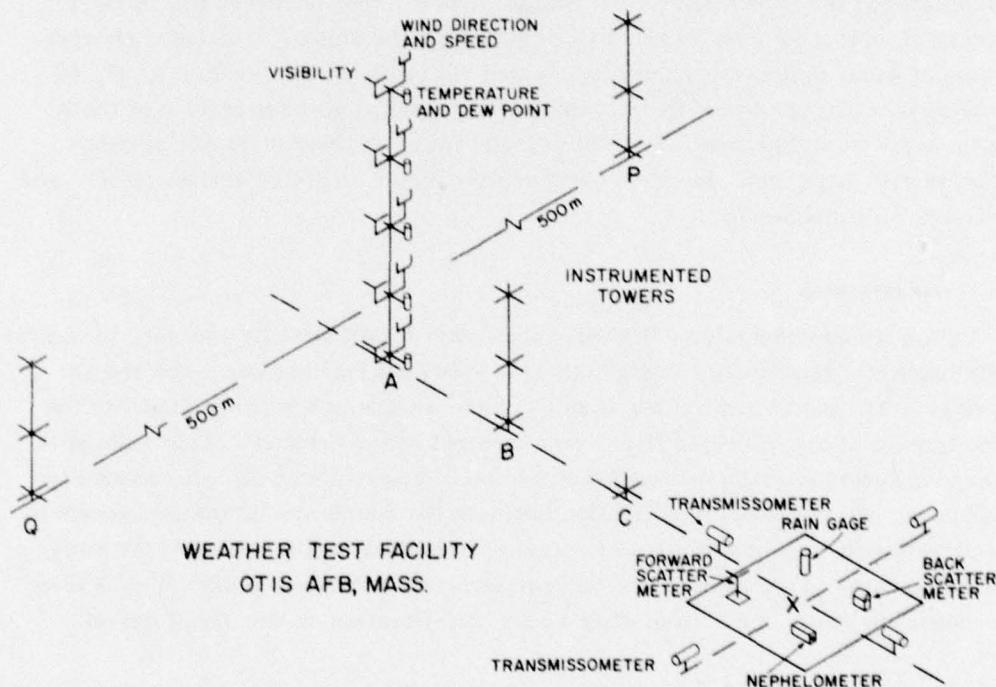


Figure 1. Configuration of Instrumented Towers and Ground Site at AFGL Weather Test Facility, Otis AFB

simulated aircraft approach zone with instrumented towers providing wind, temperature, dew point and visibility measurements to heights of approximately 60 m, 30 m and 3 m (A, B, and C, respectively). There are two instrumented 30-m towers (P and Q) located 500 m on each side of the simulated approach zone. At the southern end of the zone lies an extensive array (X) of ground-based weather instruments.

A Doric 200-channel data-logger interrogates all sensors every 12 sec (wind sets are interrogated every 6 sec), and stores the data on magnetic tape. Data tapes are then processed at Hanscom AFB on the AFGL CDC 6600 computer, edited for instrument malfunction, and converted to meteorological units.

3. DESCRIPTION OF AUTOMATED SENSORS

The main reason for automation of the present weather was to integrate it into MAWS as part of the total automation of the aviation weather observation. Since MAWS conceptually consists of a single instrumented tower (50 m) and three instrumented poles (3 m) along the main runway, this configuration was simulated at the Otis WTF. Referring to Figure 1, one observes the vertical array of instruments on Tower A as selected for the study. It includes observations of wind, temperature, dew point, and visibility at four levels (16, 29, 48 and 57 m). Ground based instruments (at 3-m elevation) were located at the X site, a horizontal separation of 290 m from Tower A, consisting of a tipping-bucket rain gage, nephelometer, back scatter meter, forward scatter meter, and two transmissometers.

3.1 Transmissometer

The transmissometer (TRANS), the standard AWS visibility sensor, measures atmospheric transmission of light along a fixed path between projector and receiver. The instrument output is an analog voltage which is proportional to the percentage of the projected light beam received at the detector. This voltage is then converted to extinction coefficient to be compatible with all other visibility sensors. An additional modification has been the conversion of the instrument to solid-state through installation of a Tasker modification kit. Some of the major disadvantages of the system are: a requirement for frequent calibration, a loss of signal in snow, and occasionally a loss of calibration during precipitation.

3.2 Forward Scatter Meter

The E. G. & G. Forward Scatter Meter (FSM) will not be discussed at length as it has been described in detail elsewhere.^{8, 9} It measures the integrated scattering coefficient between 20° and 50° of a forward directed optical beam, which is then converted to extinction coefficient, assuming the absorption is negligible. Advantages of the FSM include its small size, ease of calibration, and installation. Through many years of operation, the FSM has proved to be a reliable and accurate instrument. One problem, however, is the sensitivity of tower mounted FSM's to light scattered from reflective surfaces located in their field of view. Since the problem is unique for a given height, location, and time, it can usually be corrected by a reorientation.

3.3 Back Scatter Meter

The Impulspysics Videograph (VIDE) is a visibility meter which measures the amount of light backscattered from a projector into a photosensitive receiver located above the projector. The angle of intersection of the projector and detector provides a sample scattering volume that extends from 2 to 30 m in front of the instrument. Advantages of the instrument are its large sample volume, compact design, and ease of installation. A primary disadvantage^{9, 10} is the inherent characteristic of the VIDE to receive enhanced backscatter from falling snow. Thus visibilities obtained in snow conditions are lower than those reported by a human observer or the FSM. However, this characteristic will be used to advantage in the decision tree programs.

3.4 Nephelometer

The Meteorology Research Inc. Model 1550 Integrating Nephelometer (NEPH) has been developed in order to measure the restriction to visibility caused by atmospheric particles. An air sample is continuously drawn through a chamber where its moisture is removed (heated) and then illuminated by a pulsed flash lamp. The scattered light from all scattering angles is detected by a photomultiplier tube. The signal is averaged and compared with a "clean air" reference voltage from another photomultiplier looking directly at the flash lamp. This measurement is then output as the scattering coefficient. Since absorption by

8. Hering, W., Muench, H.S., and Brown, H.A. (1971) Field Test of a Forward Scatter Meter, AFCRL-71-0315, AD A726 995.
9. Chisholm, D. and Jacobs, L. P. (1975) An Evaluation of Scattering Type Visibility Instruments, AFGL-TR-75-0411, AD B010 224L.
10. Vogt, H. (1968) Visibility measurement using backscattered light, J. Aeronaut. Sci. 25(No. 5):912-918.

particulate matter is negligible at visible wavelengths, the scattering coefficient may be assumed to be equal to the extinction coefficient, and thus comparable to measurements made by the FSM, the VIDE and the TRANS. The principal advantage of the instrument is that the moisture of the air sample may be reduced through use of the heater and thus the extinction coefficient due to particulates alone may be obtained.

3.5 Temperature-Dewpoint Set

The E. G. & G. Model 1105-M Temperature-Dewpoint set provides accurate measurements of dew point and temperature. The dew-point measurement is made using a Peltier-cooled mirror automatically held at the dew-point temperature by means of a condensate-detecting optical system. The mirror temperature, namely, the dew-point temperature, is determined by an embedded platinum resistance thermometer. The air temperature is determined with a similar platinum resistance thermometer thermally shielded and aspirated. The temperature dew-point range is from -62°C to 49°C , with accuracies over the range of interest approximately $\pm 0.26^{\circ}\text{C}$.

3.6 Wind Direction and Speed Instrument

The Climatronics Wind Mark I Wind Set is characterized by noncontacting wind direction transducers, a solid-state light source and light weight sensors. Its advantages include low threshold (0.22 msec^{-1} for speed and 0.11 msec^{-1} for direction), fast response (7.6 m of flow maximum for 63 percent recovery), and accuracy (for wind speed, ± 1 percent or $\pm 0.07 \text{ msec}^{-1}$, whichever is greater, and for direction $\pm 2.5^{\circ}$). The instruments operate on a 0° to 540° range on the direction system; they have been modified to include heating elements along the speed and direction mounts in order to eliminate freezing.

3.7 Rain Gage

A Belfort Model 5-405 Tipping Bucket Rain Gage is being used to measure the presence and intensity of precipitation. In the winter months, the unit is heated, in order to measure melted precipitation. The instrument has been calibrated to tip each time 0.127 mm (0.005 inch) is received from the 305 mm (12-inch) diam collector. In order to maintain a check on the accuracy of the instrument, two Belfort Weighing Bucket Rain Gages with strip chart recorders are mounted in proximity.

4. WEATHER DISCRIMINATION BY SENSORS

Comparative analyses of some of the visibility sensors have been accomplished and reported by several investigators. The FSM was compared with the TRANS in field studies in 1970 and in 1974.^{8, 11} Correspondence between the instruments was rated as very good with correlation coefficients ranging from 0.91 to 0.98 and standard errors of estimation ranging from 12 to 26 percent. The VIDE has been compared to human visibility observations; it has been found to have an error of estimation of about 20 percent in fog. However, in snow,⁹ the VIDE indicated a lower visibility as compared to other sensors. The NEPH also has been examined by several investigators, Tombach¹² in 1971, and Charlson and Waggoner in 1974;¹³ it has been found to give a representative measure of the restriction to visibility due to particulate forms.

4.1 Scatter Diagram Analysis

In the preliminary phase of this study, comparative observations were made under a variety of weather conditions at the Otis WTF, in order to establish criteria for the decision tree model program. An example of the relationship between the FSM and the TRANS (Figure 2) shows the linearity over a wide range of extinction coefficient, lack of scatter, and good agreement with previous comparisons. This particular sample, 2372 minutes of fog over a two-day period, has a correlation coefficient of 0.99 and a standard error of estimate of 18 percent.

Comparison of VIDE and FSM during the same period reveals a nonlinear relationship between the instruments, below an extinction coefficient of $10 \times 10^{-4} \text{ m}^{-1}$ (or above a sensor equivalent daytime visibility of approximately 3 miles). The correlation (Figure 3) for the reduced sample (excluding FSM values below $10 \times 10^{-4} \text{ m}^{-1}$) compares well with other studies and, in this case, is 0.97 with a standard error of estimate of 16 percent. The calibration equation obtained as a result of these comparisons in fog was retained as the principal equation for translation of VIDE voltage readings in all restrictions to extinction coefficient.

The next tests were comparisons of the TRANS and VIDE with the FSM during periods of snow. The first scatter diagram (Figure 4) shows the excellent correlation (0.99) of the TRANS with the FSM, a slope of the least squares line of 0.97,

11. Muench, H.S., Moroz, E.Y., and Jacobs, L.P. (1974) Development and Calibration of the Forward Scatter Visibility Meter, AFCRL-TR-74-0145, AD 478 3270.
12. Tombach, Ivar (1971) Measurement of Some Optical Properties of Air Pollution With the Integrating Nephelometer, AIAA Paper No. 71-1101, Joint Conference on Sensing of Environmental Pollutants.
13. Charlson, R.J., and Waggoner, A.P. (1974) Visibility, aerosol, and colored haze, No. 74-261, Proc. Air Pollution Control Association.

SCATTER DIAGRAM

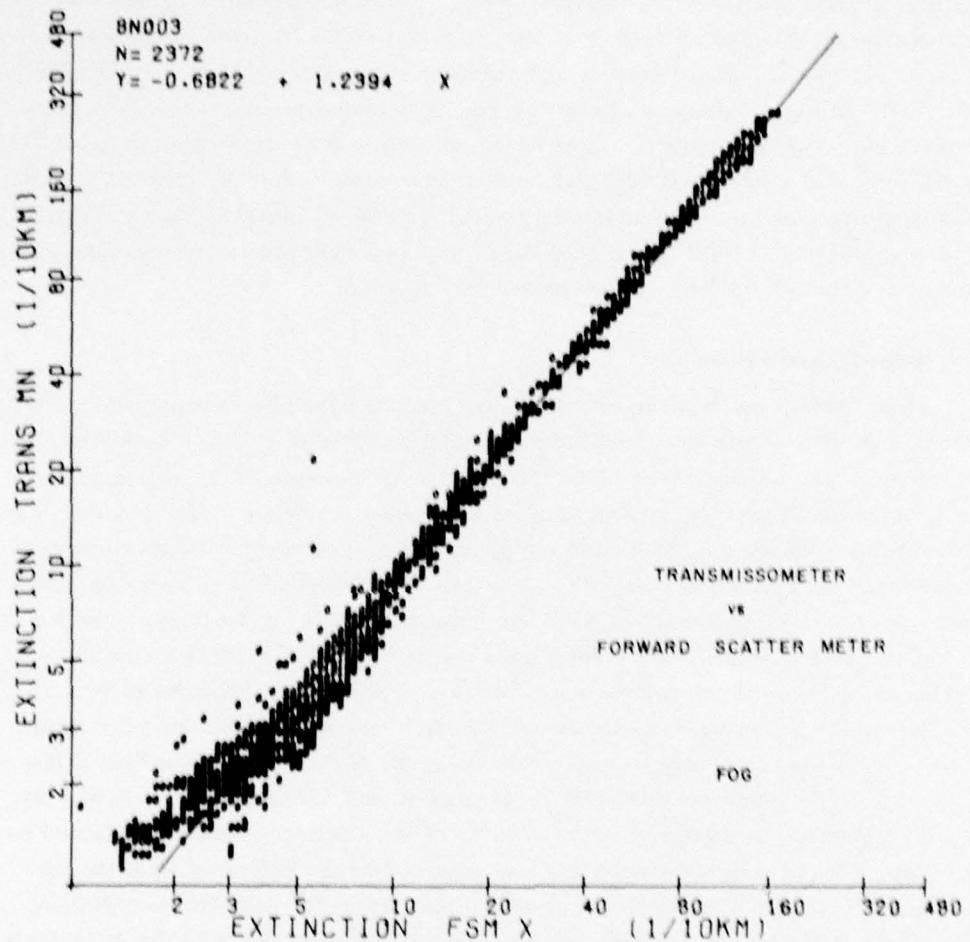


Figure 2. Comparison between Transmissometer and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Fog

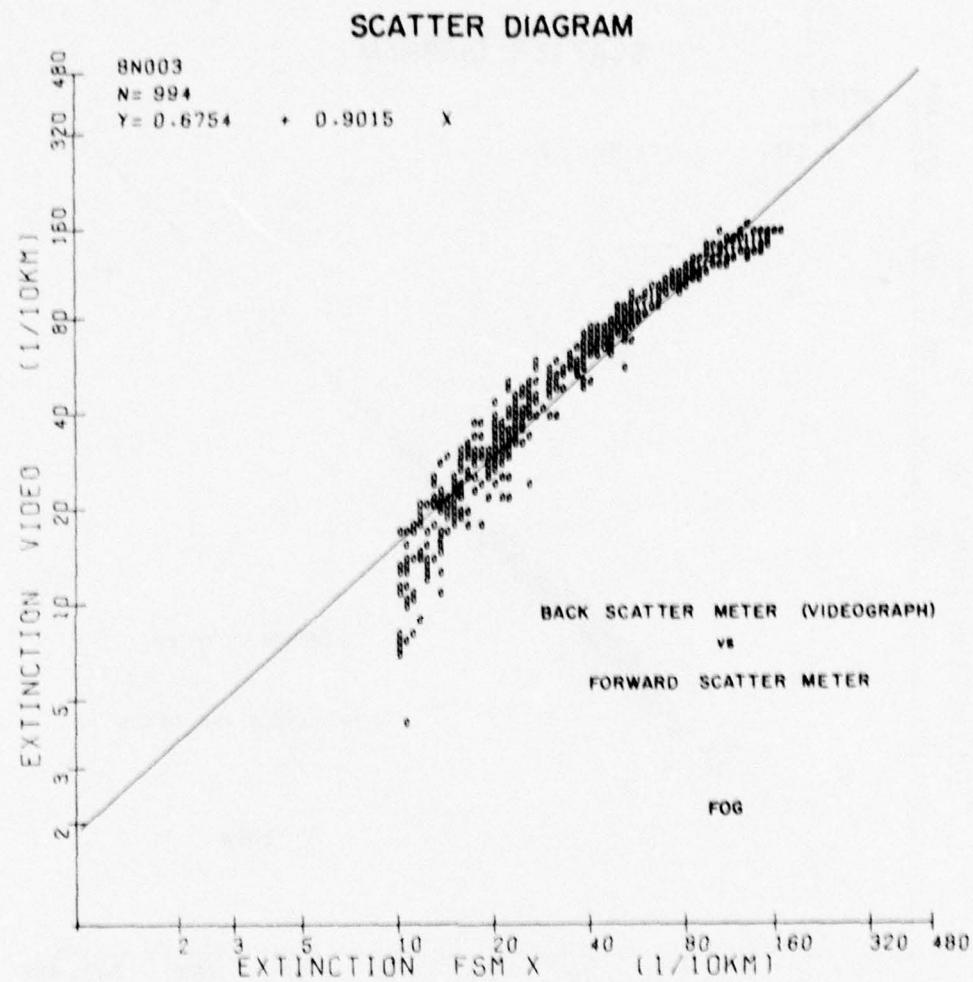


Figure 3. Comparison between Back Scatter Meter (Videograph) and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Fog

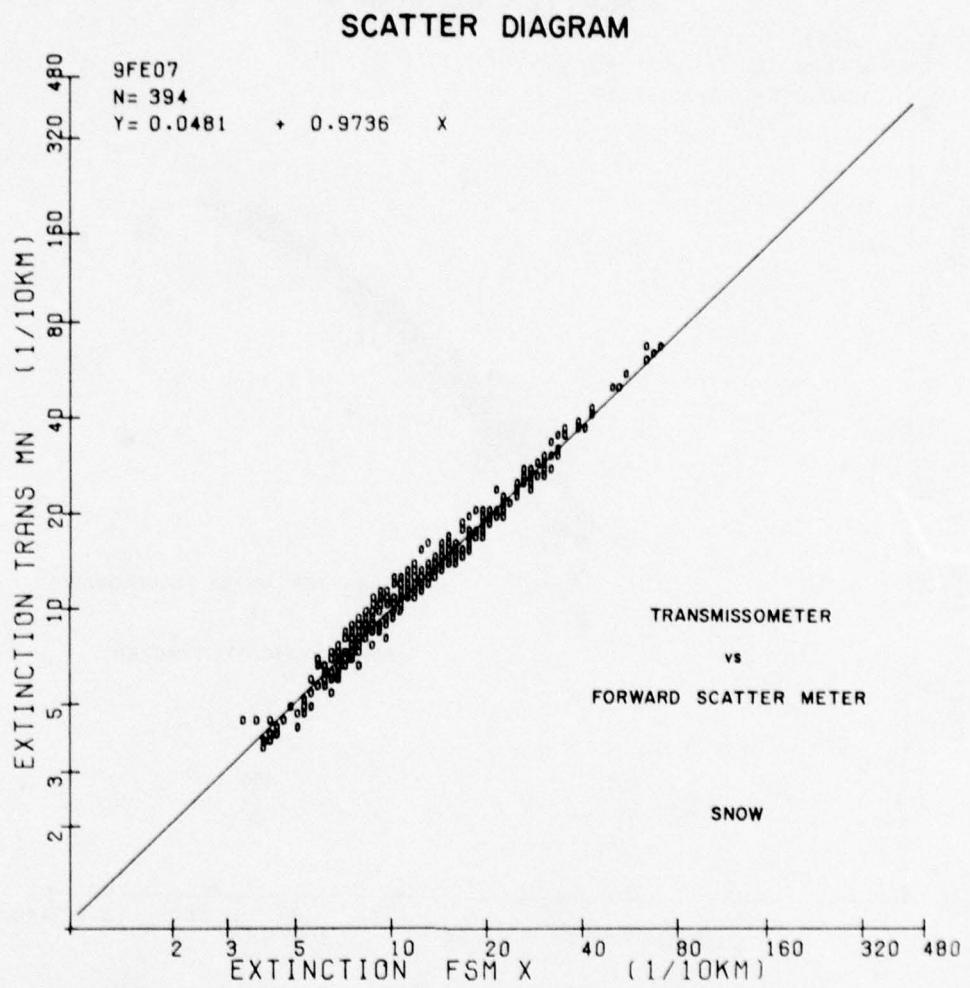


Figure 4. Comparison between Transmissometer and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Snow

and a standard error of estimate of 8 percent. The next diagram (Figure 5) graphically illustrates the tendency of the VIDE, using the fog-derived calibration, to denote higher extinction coefficients (thus lower visibilities) than the FSM during snow. The correlation coefficient is 0.84 and the standard error of estimate is 28 percent. Finally, two scatter diagrams (Figures 6 and 7) illustrate the relationships between the FSM and TRANS during periods of rain and drizzle. Cursory examination of these instruments during periods of inclement weather would lead to the suggestion that the FSM consistently records higher extinction coefficients than the TRANS during periods of rain. However, during periods of drizzle, the TRANS and FSM correlate essentially one to one. This is clearly illustrated in Figure 6, where, for example FSM extinction coefficients of 20 and $40 \times 10^{-4} \text{ m}^{-1}$ relate to TRANS readings of 12 and $23 \times 10^{-4} \text{ m}^{-1}$ during rain, whereas in drizzle (Figure 7) the same FSM extinction coefficients correspond to extinction coefficients of 18 and $34 \times 10^{-4} \text{ m}^{-1}$ for the TRANS. In general, the slope of the least squares line of best fit in drizzle more closely approximates 1, whereas in rain, slopes are more on the order of 0.8 to 0.9.

4.2 Time Section Analysis

Upon completion of the instrumental comparative phase of the study (Section 4.1), examination of height and time variations of the instrument readings was made during a variety of weather conditions. Several needs for the decision tree program could thus be satisfied: First, it was essential to determine an estimate of the frequency necessary for updating the automated weather observations; second, it was necessary to demonstrate through time series plots further reinforcement of the characteristic response differences of certain instruments to the same phenomena, in particular, the NEPH and FSM in fog and haze, and the VIDE and FSM in snow; and third, information was needed on the vertical gradients in fog and ground fog to determine decision tree criteria. Finally, as a preliminary to determining a verification routine, it was necessary to relate the instrument output to human observations.

The first time series section (Figure 8) gives a detailed view of the vertical variation of the extinction coefficient from the lowest level (FSM X-3 m) to the highest instrumented level on Tower A (A-200). The time period extends over five hours. For reference, an extinction coefficient of $30 \times 10^{-4} \text{ m}^{-1}$ denotes a nighttime sensor equivalent visibility (SEV) of approximately 1-1/4 mile while an extinction coefficient of $210 \times 10^{-4} \text{ m}^{-1}$ represents a nighttime SEV of about 3/16 mile. Just above the time scale are hourly and special weather observations made by the FAA observer at Otis AFB. The FAA observation point is atop an 85-ft tower, located 1.2 miles east of the Weather Test Facility. Figure 8 shows that the FAA observer was reporting an obstruction to vision of fog and

SCATTER DIAGRAM

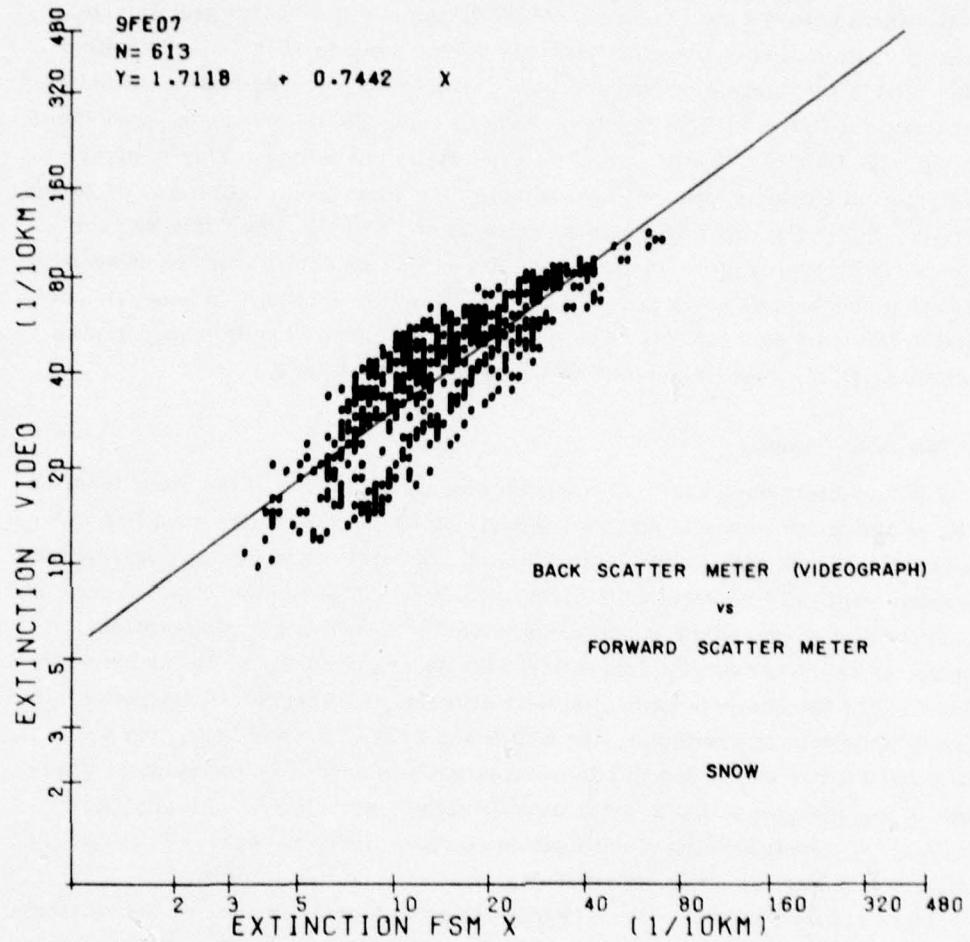


Figure 5. Comparison between Back Scatter Meter (Videograph) and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Snow

SCATTER DIAGRAM

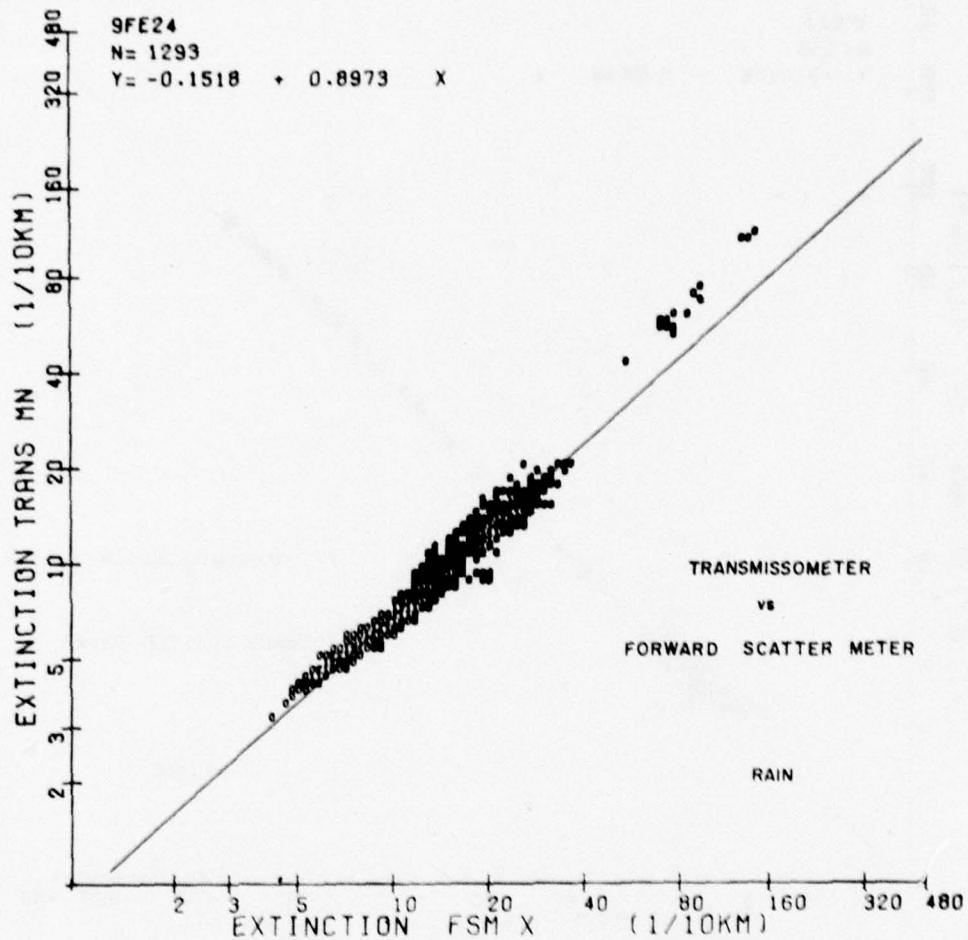


Figure 6. Comparison between Transmissometer and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Rain

SCATTER DIAGRAM

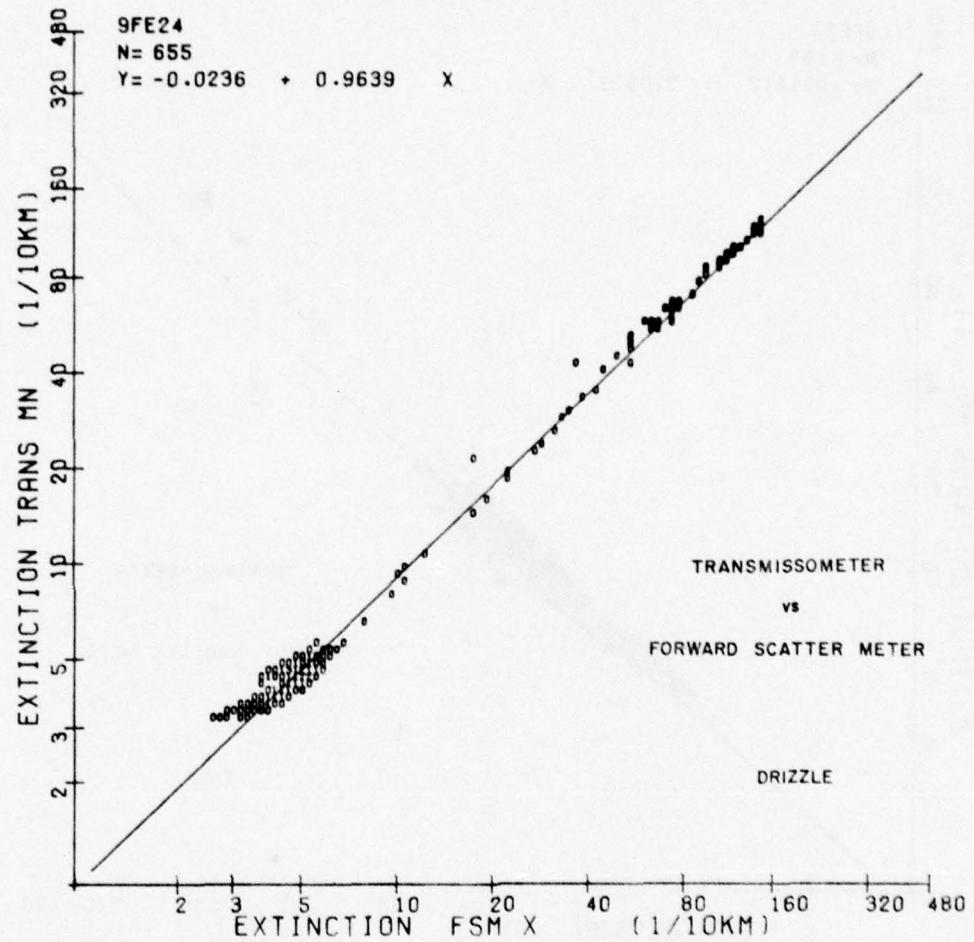


Figure 7. Comparison between Transmissometer and Forward Scatter Meter Measurements (1-min Averages) of Atmospheric Extinction Coefficient during Drizzle

TIME SECTION OF EXTINCTION COEFFICIENT

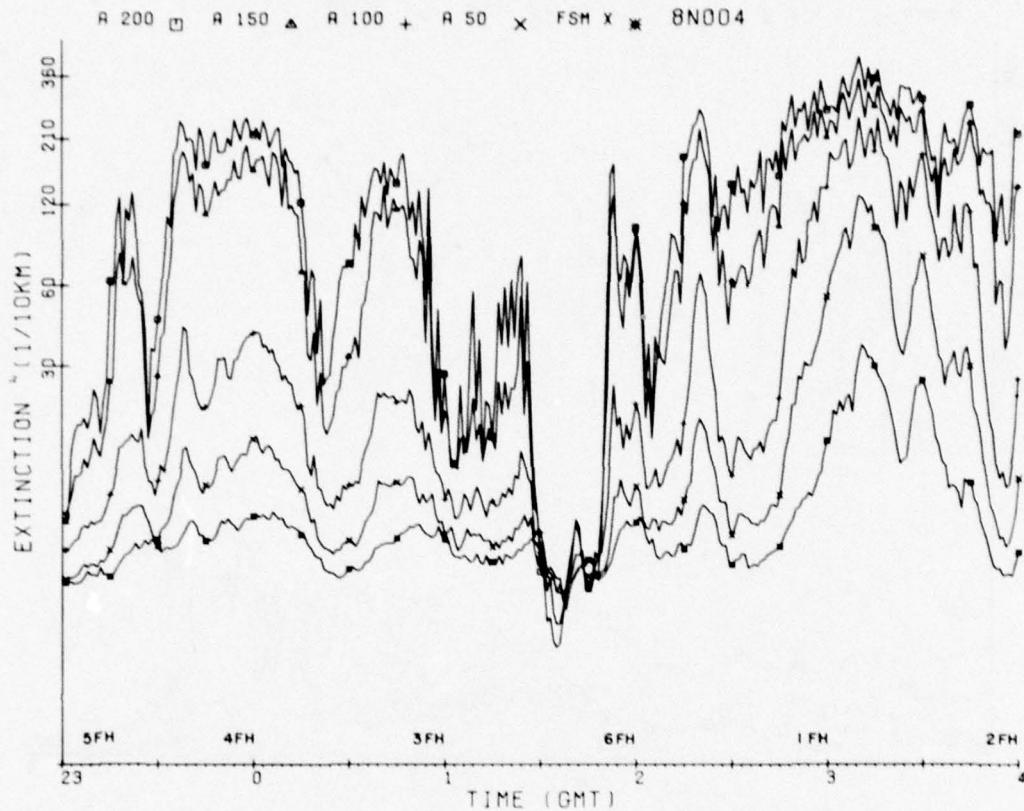


Figure 8. Time Series of Atmospheric Extinction Coefficient (1-min Averages) Measured by Forward Scatter Meter at the 57-m (A-200), 48-m (A-150), 29-m (A-100) and 16-m (A-50) Levels of Tower A and at the 3-m (FSM X) Level of Ground Site X on 4-5 November 1978 during Fog. FAA Weather Observation made at Otis AFB are plotted above the time axis

haze for the entire period, with prevailing visibility values varying from one to six miles.

One of the features to be noted on this typical fog case is the strong vertical gradient of visibility between the 3 m-level (FSM X lower curve) and the 57-m level (A-200 upper curve). Of significant importance are the large and rapid fluctuations of visibility that can occur during a five-hour period with fog.

The second time series section (Figure 9) illustrates the extinction coefficient during a period of ground fog. It can be seen that the gradient of visibility has reversed. The uppermost curve now denotes the visibility at 3-m (FSM X), whereas the lowest curve represents the 57-m level (A 200). The FAA observer reported prevailing visibilities ranging from 10 to 14 miles and noted ground fog

TIME SECTION OF EXTINCTION COEFFICIENT

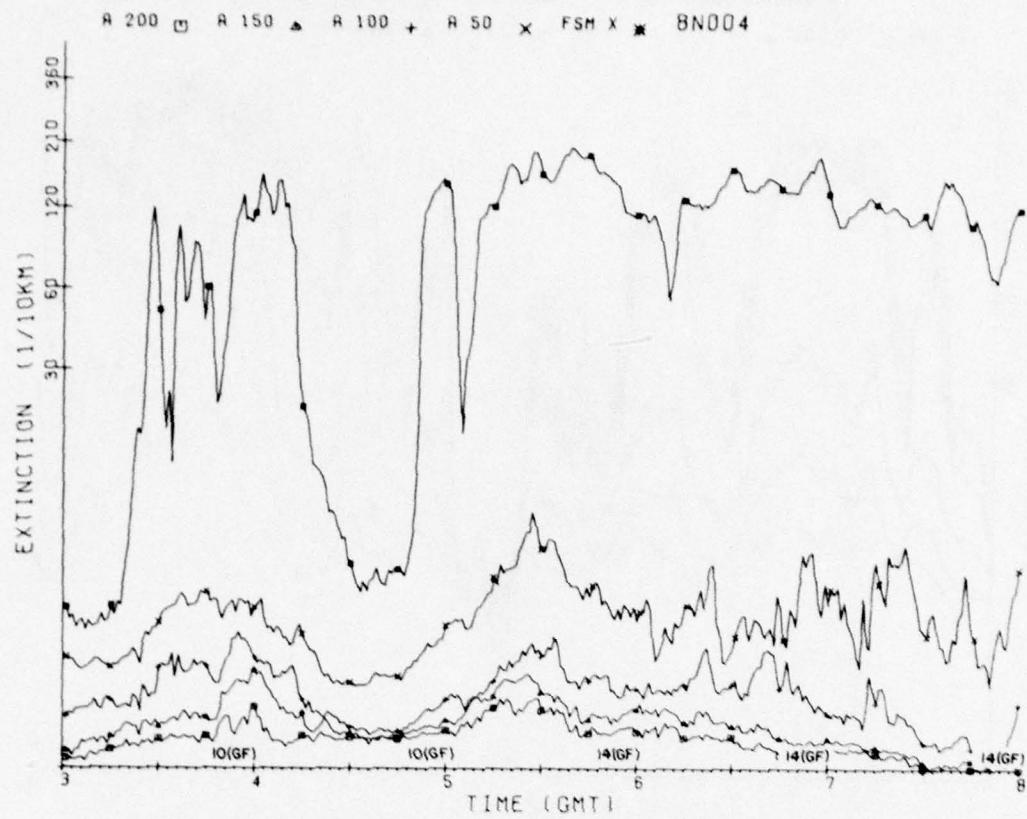


Figure 9. Time Series of Atmospheric Extinction Coefficient (1-min Averages) Measured by Forward Scatter Meter at the 57-m (A-200), 48-m (A-150), 29-m (A-100) and 16-m (A-50) Levels of Tower A and at the 3-m (FSM X) Level of Ground Site X on 4 November 1978 during Ground Fog

in all quadrants in his remarks. It is clear from an examination of the extinction coefficient at different height levels that the ground fog was apparent to a small degree even at the 57-m level (A 200).

The response of the nephelometer was also investigated during periods of fog, and periods of fog and haze. Figure 10 shows a sample period when the FAA was reporting fog with visibilities of 2-1/2 miles. The FSM's at 3, 29 and 57 meters (FSM X, A100, and A200) were recording extinction coefficients typical of fog, whereas the NEPH was recording an extinction coefficient caused by particulate matter of $4 \times 10^{-4} \text{ m}^{-1}$ which is a nighttime SEV of about 6 miles.

TIME SECTION OF EXTINCTION COEFFICIENT

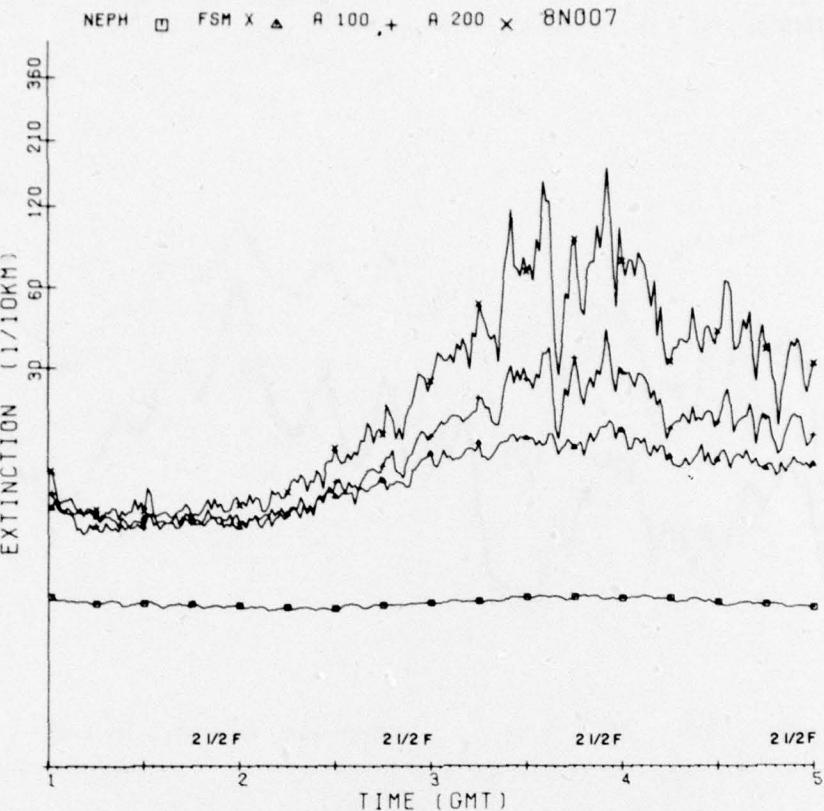


Figure 10. Time Series of Atmospheric Extinction Coefficient (1-min Averages) Measured by Forward Scatter Meter at the 57-m (A-200) and 29-m (A-100) Levels at Tower A and at the 3-m (FSM X) Level at Ground Site X and also by Nephelometer (NEPH) at the 3-m Level at Ground Site X on 7 November 1978 during Fog. FAA Weather Observation are plotted above the time axis

The final time series section (Figure 11) shows the variation of extinction coefficient during a snowstorm. Certain striking features are immediately apparent. The vertical variation of visibility as represented by three FSM's at 3, 29 and 57 m (FSM X, A100, A200) is essentially zero, and there is a remarkable periodicity of visibility to which each instrument is responding. The upper curve represents the time variation of extinction coefficient measured by the VIDE and calculated using the fog-calibration equation. It dramatically shows the tendency of the VIDE to underestimate the visibility during snow. It should be noted, however, that there is excellent agreement between the VIDE and FSM in representing the time variations. The FAA observer in this case made a commendable effort to keep up with the rapidly fluctuating visibility.

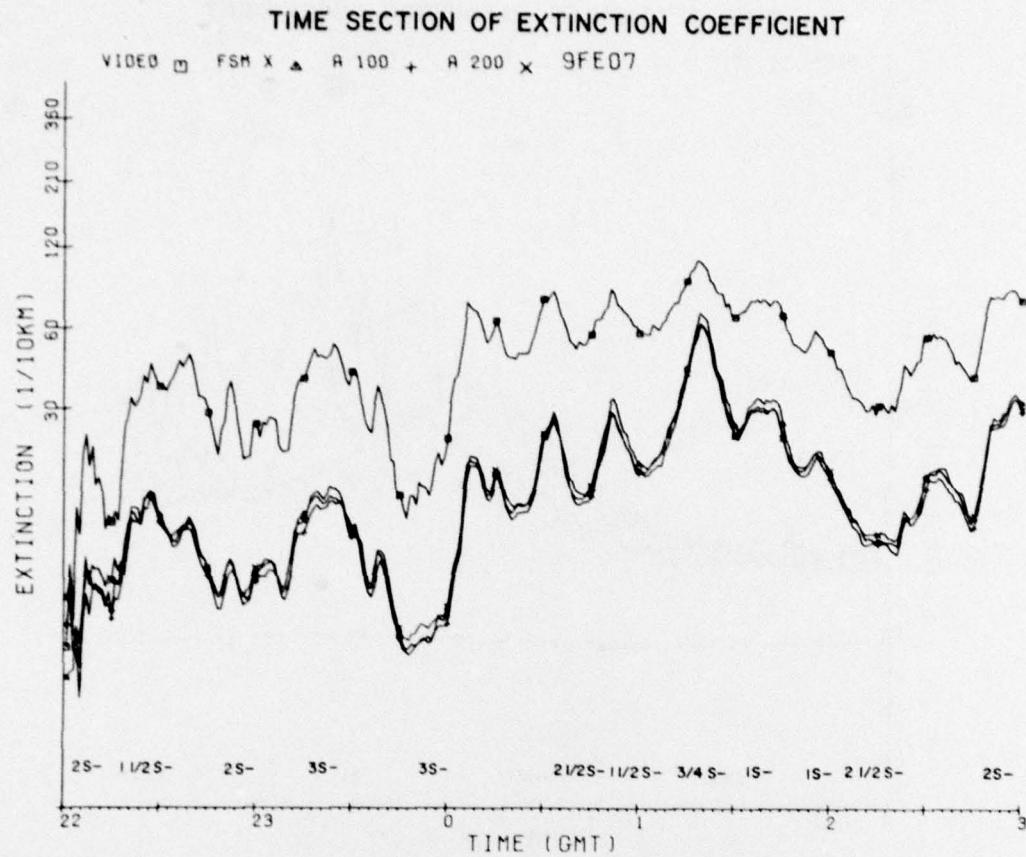


Figure 11. Time Series of Atmospheric Extinction Coefficient (1-min Averages) Measured by Forward Scatter Meter at the 57-m (A-200) and 29-m (A-100) Levels at Tower A and at the 3-m (FSM X) Level at Ground Site X and also by Back Scatter Meter (VIDEO) at the 3-m Level at Ground Site X on 7 February 1979 during snow. FAA weather observations are plotted above the time axis

5. PRESENT WEATHER DECISION TREE PROGRAM

5.1 Selection of Weather Elements

Present-day aviation weather observations conform to rules that are based on agreements with the World Meteorological Organization, international and domestic aviation interests, as well as civil and military weather services. Of the required components that make up an aviation weather observation, only one, weather and obstruction to vision, is being addressed in this report.

Figure 12 represents a list of weather and visibility restricting elements currently in use. The observer is required to select from this list the most appropriate items that describe the occurring weather phenomena. The symbols and descriptive titles are self-explanatory. The lower list of intensity symbols are used in conjunction with the precipitation symbols to indicate light, moderate, or heavy. By agreement, hail (A) and ice crystals (IC) are not assigned any intensity.

WEATHER SYMBOLS

T	Thunderstorm	O	RW	Rain Showers
T+	Severe Thunderstorm	●	S	Snow
A	Hail		SG	Snow Grains
IC	Ice Crystals		SP	Snow Pellets
IP(W)	Ice Pellets(Showers)	O	SW	Snow Showers
● L	Drizzle	●	ZL	Freezing Drizzle
● R	Rain	●	ZR	Freezing Rain

OBSTRUCTIONS TO VISION

● BD	Blowing Dust	● H	Haze
● BN	Blowing Sand	D	Dust
● BS	Blowing Snow	● F	Fog
● BY	Blowing Spray	● GF	Ground Fog
● K	Smoke	● IF	Ice Fog

PRECIPITATION INTENSITY SYMBOLS

--	Very light	●	Absence of symbol indicates moderate except for A and IC
● -	Light		
● +	Heavy		

Figure 12. Symbols for Weather, Obstructions to Vision and Precipitation Intensity. Closed circles opposite symbols denote inclusion in the Present Weather Program. Open circles denote inclusion through observational frequency. (From Federal Meteorological Handbook No. 1)

The challenge to automation is the discrimination of as many of these elements shown in Figure 12 as possible. Considerable argument could be generated on the priority of the individual elements and, in some cases, the necessity. Suffice it to say that a basic automated weather program should include thunderstorms, hail, solid precipitation, and finally liquid precipitation. A basic obstruction to vision program should contain elements to denote visibility restriction by suspended particles, fog, blowing snow, and blowing particles. The precipitation intensity symbols denoting light, moderate, and heavy are also essential. Careful consideration of the instruments and the preliminary analyses led to the choice of the elements to be automated by the decision tree program. Those selected are marked with a closed circle just to the left of the element. Open circles are placed by rain showers and snow showers to denote partial coverage because observations were to be made on a minute-to-minute basis.

The two major elements unobserved by the automated program are thunderstorms and hail. Developments in this area, however, are continuing. Instruments for example, have been designed to measure the momentum imparted to a platform by a hailstone strike. One instrument described by Dennis et al¹⁴ appears to be capable of automation. Several passive thunderstorm warning systems have been designed and are available, in addition to the better known nonpassive system, radar. One, described by Petrocchi and Paulsen,¹⁵ consists of an electrostatic and an electromagnetic detector channel which presents a continuous measure of local electric field strength and which also counts lightning strikes and determines their distance from the sensor.

5.2 Obstruction to Vision Program

Figure 13 illustrates, by means of a simplified flow diagram, the decision tree program which is comprised of two major phases. The obstruction to vision phase, shown at the top of Figure 13, initially considers the measurement of extinction coefficient to determine if the visibility is less than 7 miles (11 km). Granted that it is, an examination of the dew-point spread determines whether one proceeds down the "dry" or "moist" branch of the decision tree. A temperature dew-point spread greater than 6°C defines dry conditions, after which tests are made on gustiness, vertical profiles of extinction coefficient and nephelometer values in order to discriminate haze from blowing dust, or in some cases, blowing snow. If the temperature dew-point spread is less than 6°C , then the flow is

14. Dennis, A.S., Smith, P.L., Peterson, G.A.P., and McNeil, R.D. (1971) Hailstone size distributions and equivalent radar reflecting factors computed from hailstone momentum records, *J. Meteorol.* 10:79-85.
15. Petrocchi, P.J., and Paulsen, W.H. (1973) Lightning Warning Set Test Report, AFCRL-TR-73-0370, AD A770 014.

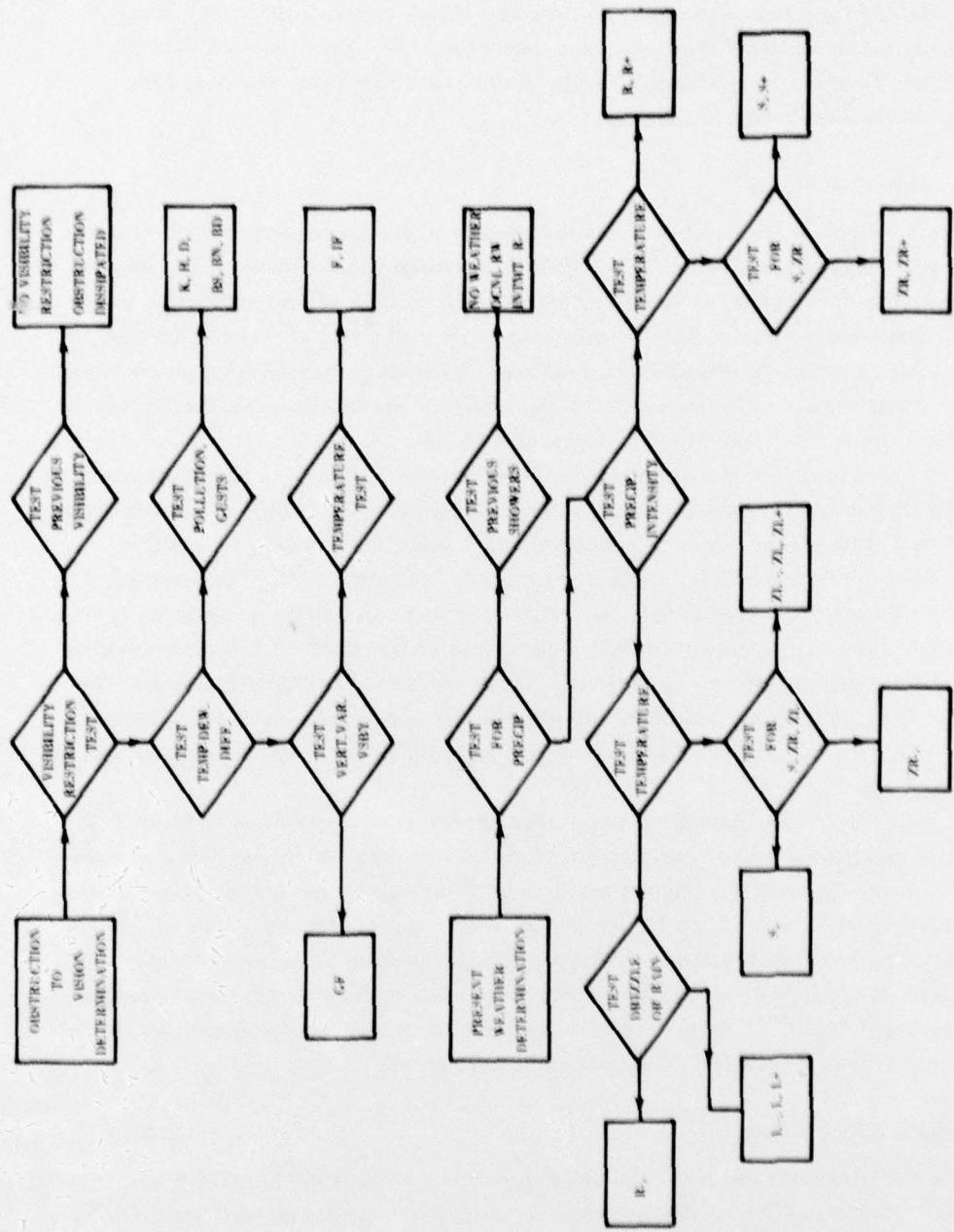


Figure 13. Flow Charts of Obstruction to Vision and Present Weather Determination Program

directed to a determination of the vertical gradient of extinction coefficient. If the uppermost extinction coefficient is significantly less (60 percent) than the lower, then ground fog is selected as the obstruction type. If the upper level extinction coefficient is similar to, or greater than the lower level extinction coefficient, then fog is selected. Temperature tests are also considered to determine the rare event of ice fog.

5.3 Present Weather Program

The present weather phase of the decision tree program, shown in the lower half of Figure 13, is activated by one tip of the heated tipping-bucket rain gage. A validity check is accomplished by examining the profile of four extinction coefficients and requiring that all be greater than $1.4 \times 10^{-4} \text{ m}^{-1}$. This value was determined empirically through examination of extinction coefficient data collected earlier. The next step is to determine the liquid or melted precipitation intensity from the number and time of occurrence of rain tips.

When precipitation is determined to be moderate or heavy, a temperature check is then made to separate freezing from liquid precipitation. If the temperature is 0.5°C or higher, rain is identified and a final test is made to identify steady rain or rain showers. If the temperature is below 0.5°C , tests are performed to determine whether the precipitation is to be identified as snow or freezing rain. If the extinction coefficient determined by the VIDE is 50 percent higher than the FSM values, snow is identified. If the two are approximately equal, the program selects freezing rain with the previously determined intensity. Snow intensity is determined by visibility criteria established in the Federal Meteorological Handbook.¹⁶

In the case of light precipitation, a test of temperature relative to the 0.5°C threshold separates liquid precipitation from the freezing or frozen type. A comparison of the FSM and TRANS extinction coefficient discerns drizzle from rain. If the FSM value is more than 15 percent greater than the TRANS value, then rain is selected; otherwise drizzle is selected. When freezing or frozen precipitation is present, a similar set of tests is accomplished to differentiate freezing rain and freezing drizzle. A further test is required for snow, which is similar to the VIDE vs FSM test described in the previous paragraph.

5.4 Examples of Observations

The decision tree program produces minute-by-minute observations of weather. These in turn are being compared with the operational weather

16. Federal Meteorological Handbook No. 1 (1972) Surface observations, A3, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.

observations made by FAA Control Tower personnel at Otis AFB. Two 1-hour samples of the program's output were selected to demonstrate the 1-min observations deduced by the decision tree; to illustrate the comparative FAA observations; and to show the program's responsiveness to changing weather and its stability in homogeneous conditions.

The first sample shown in Figure 14, column 1, denotes the time of observation to the nearest minute; columns 2 through 6 are 1-min averages of extinction coefficient ($\times 10^{-4} \text{ m}^{-1}$) measured by the FSM at four levels of tower A (A 200-57 m, A 150-48 m, A 100-29 m, A 50-16 m and at X-3 m). Column 7 is the TRANS extinction coefficient; columns 8 through 17 show the 1-min averages of temperature ($\times 10^0 \text{C}$) at the FSM levels of tower A, followed by the temperature dew-point difference at the same heights. Column 18 is a 1-min count of the number of tips made by the rain gage in response to precipitation. Column 19 shows the extinction coefficient obtained from the NEPH. Column 20 displays the VIDE extinction coefficient observation. Column 21 shows the determination by the decision tree of present weather and/or obstruction to vision. The last column shows the present weather observations taken by the FAA observer during this hour. Symbols shown here denote rain (R), fog (F) and drizzle (L).

Note the low extinction coefficient (good visibility) on the tower (columns 2 through 5) during the first thirty-five minutes of the hour, followed by an abrupt increase at about 2039Z. The weather program, which had been reporting No Weather (col 21), verified the data as valid, scanned the temperature and noted a range between 17.3° to 18.6°C with dew-point spreads to 2.5° to 3.7° . It then checked and found no precipitation and chose fog (F) as the obstruction to vision. Two minutes later the first rain tip occurred (col 18) and within a few minutes moderate rain with fog was observed. Heavy rain (R+) was observed twice during the hour and drizzle once, at 2042Z. The FAA observer recorded one observation during the hour at 2055Z, some 12 minutes after moderate rain started, and it was moderate rain with fog. One hour earlier, at 1955Z, he had recorded No Weather as had the present weather program.

The second example, Figure 15, shows data collected on 7 November 1978 between 0200 and 0300Z. Note here the increase in extinction coefficient with time and height, the temperature range between 12° and 13°C and the dew-point spread of 1° to 1.5°C . A minus sign before the dew-point spread is treated as the equivalent of zero temperature dew-point difference. Rain did not occur during the hour and the NEPH recorded an extinction coefficient due to particles of $4 \times 10^{-4} \text{ m}^{-1}$. Thus the present weather program determined the presence of fog and haze each minute of the hour. The FAA observer, at 0255Z, recorded an observation that noted fog alone.

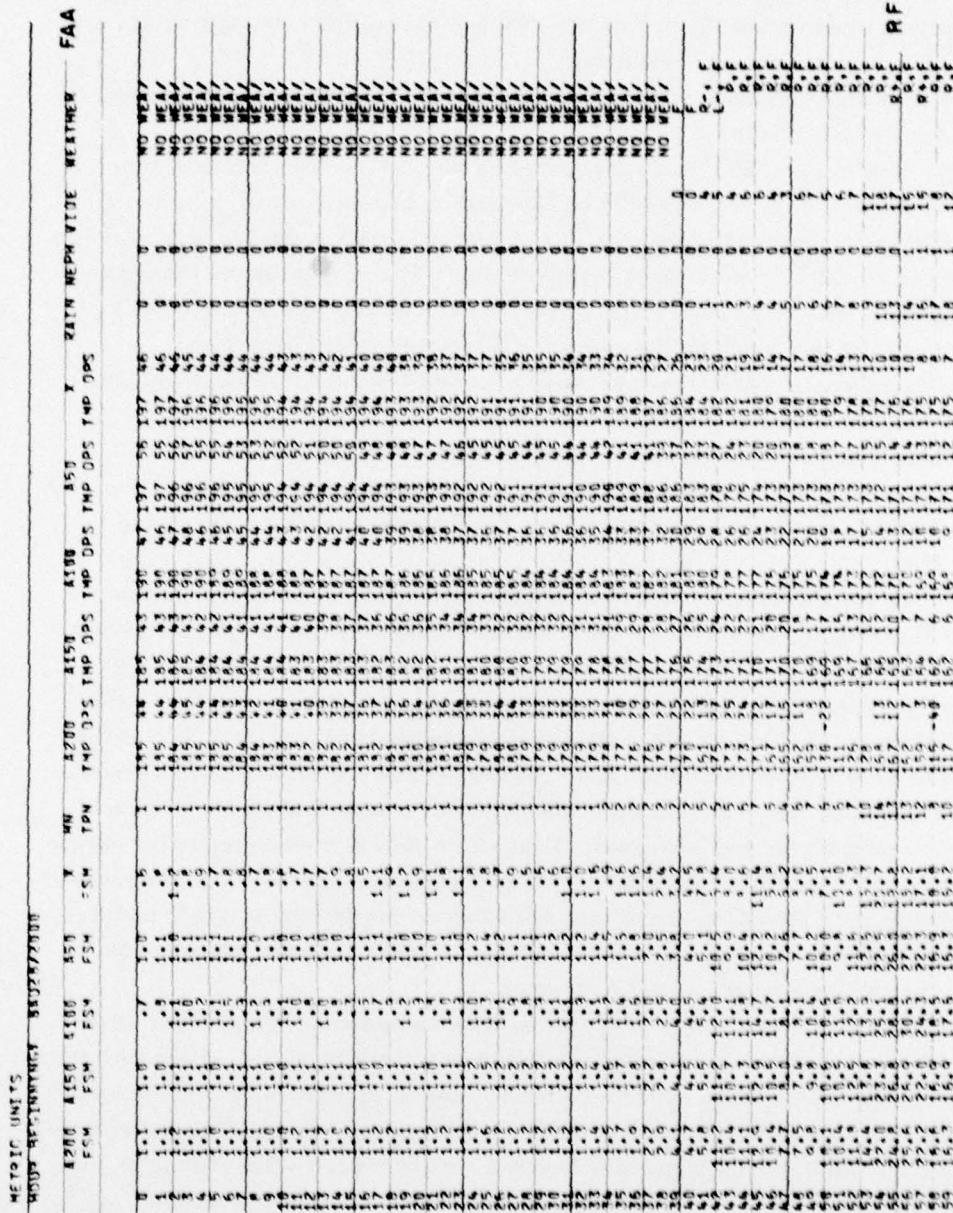
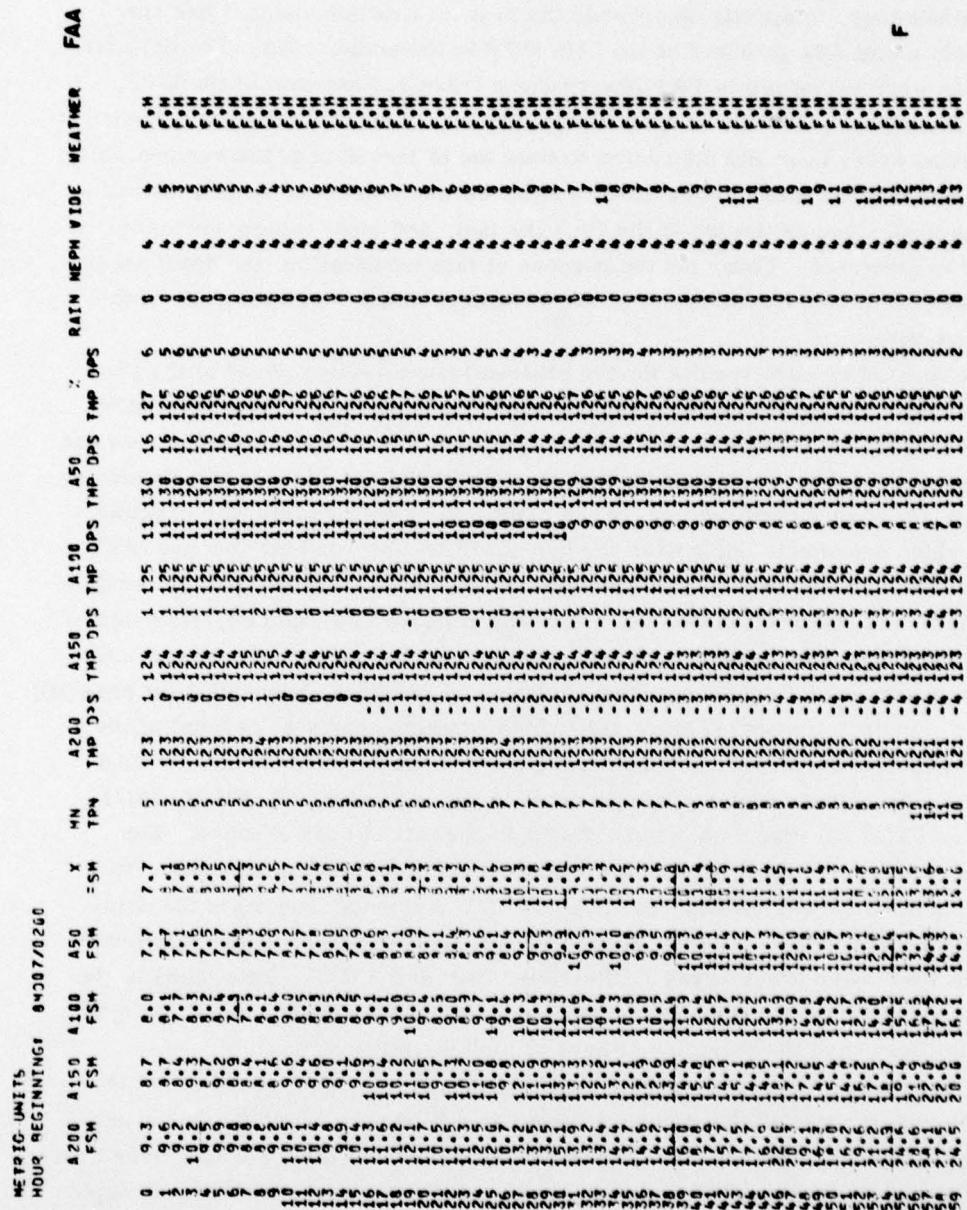


Figure 14. Example of One Hour of Present Weather Program Output at 2000 GMT, 28 August 1978. FFA weather observations are plotted at extreme right



5.5 Preliminary Results

The capacity of the present weather program (PWP), that is, the decision tree methodology, to specify objectively the present weather element has been examined, using data gathered at the Otis WTF in November 1978. The objective estimates were compared to FAA observations taken 1.5 km east of the WTF. The FAA observer, as well as all other observers, is required to take a record observation every hour and instructed to time the observation of the various elements, allowing not more than a 15-min lapse between start and finish. In addition, the time noted on the log is the time the last, and most rapidly changing element is observed. Thus, for the purpose of this verification, the PWP observation was taken as representative of the 15-min period prior to the time of the FAA observation.

The November 1978 results for the obstructions-to-vision phase of the program are summarized in contingency table form in Figure 16. No precipitation verifications are presented because the frequency of occurrence is so low that one complete year of data would be required for meaningful results. In the discussion of Figure 16, elements of the matrix are identified by coordinates; for example, F/FH, which coordinate designates the column (FAA observation) and row (PWP observation). The table is comprised of seven elements, together with no weather (NO WX) and no observation (NO OB). For the purpose of simplicity, elements of the matrix will be designated by coordinates that denote the element determined by the FAA observation first [of fog (F)], followed by the PWP observation [of haze (H)].

The principal diagonal (Figure 16), which contains nearly 85 percent of the data, shows the number of hours reflecting perfect agreement between the FAA and PWP. No further analysis will be made in the case of H/FH, FH/H, FH/F, F/FH, or F/GF because a common element is present in each of these. The areas of concern are those that do not contain a common weather element. In examining the data that made up the F/H and H/F elements, one notes the principal differences in the visibility values. In all cases the visibilities reported by FAA and PWP were lower in the F/H element than in the H/F. This leads to the possible explanation that the human observer exhibits bias in the choice of fog at low visibilities, and the selection of haze at high visibilities.

An examination of two elements, NO WX/FH and NO WX/F reveals that the FAA was reporting visibilities during these periods on the order of 7 to 8 miles. It was expected that differences of this type would occur at the threshold (less than 7 miles) that requires an obstruction to be reported. A similar reason was noted on the two elements, H/NO WX, and FH/NO WX where the FAA observed visibilities of 5 to 6 miles, whereas the PWP was recording sensor equivalent visibilities of slightly more than 7 miles.

FAA OBSERVATION

NOVEMBER 1978

AUTOMATED OBSERVATION (PWP)	IF	BN	BS	H	FH	F	GF	NO	NO
	IF	BD	BS	H	FH	F	GF	WX	OB
IF									
BN-BD									
BS									
H				2	2	3			
FH				3	7	20		6	
F				3	14	108		45	
GF						6	9	3	
NO WX				4	1			468	3
NO OB								13	

Figure 16. Example of Verification of One Month (November 1978) of Obstructions to Vision Observations Generated by Present Weather Program with FAA Weather Observations

The three observations in the NO WX/GF element were caused by the horizontal separation between the FAA and the WTF. The onset of a ground fog was first observed at the WTF and somewhat later at the FAA. Finally, the NO OB row, together with column elements, denotes the amount of time during this particular month that observations were not available from the respective sources.

6. CONCLUSIONS

The extensive array of automated weather sensors operated at the Weather Test Facility at Otis AFB, Massachusetts provides an excellent platform for detailed investigation of the automation of aviation weather observations. Preliminary analysis of data collected during November 1978 has demonstrated the feasibility of automating the determination of the obstruction to vision element by means of an objective decision tree program.

The decision tree procedure is designed to take advantage of several uniquely different responses to the same weather phenomena by certain weather sensors previously recognized and quantified. These include characteristic differences between measurements from the FSM and VIDE in snow, the FSM and TRANS in rain, the FSM and NEPH in fog and the similarity between them in haze, the contribution of vertical gradients of extinction coefficients in fog versus ground fog decisions, and others.

In conclusion, it has been demonstrated that signals from an automated array of weather sensors with differing responses to the same weather phenomena can be used in a decision-tree computer program to identify the weather type. These preliminary results show that clear weather, fog, ground fog, haze, and rain can be identified by the decision tree program. Verification of one year's observation by the PWP with those taken by the FAA is under way. This will be the subject of a later report.

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